Joint Special Interest Group meeting between euspen and ASPE
Dimensional Accuracy and Surface Finish in Additive Manufacturing,
KU Leuven, BE, October 2017
www.euspen.eu

Surface finish of additively manufactured parts using plasma electrolytic polishing

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Abstract
Additive manufacturing (AM) is considered a disruptive or key enabling technology. Polymer based AM using filament extrusion has attracted much attention from customer/maker side, but many industrial applications require parts made in metallic materials and consequently powder based processes. While these AM (SLM, EBM, DMD) processes become more and more reliable and the achievable accuracy shifts towards industrial applicability, the achievable surface quality is still insufficient. This process inherent challenge is based on partial melting and/or agglomeration of powder to the outside of the melt pool and the part, leading to high roughness values in the range of 10 µm ≤ Ra ≤ 30 µm. In combination with AM-specific complex designs (i.e. "complexity for free" approach) and the resulting inaccessibility of many surfaces for e.g. grinding tools, surface finishing to acceptable values of Ra ≤ 2 µm is difficult.
The recently developed Plasma electrolytic Polishing (PeP) process is based on a high DC voltage applied between part and an aqueous electrolyte and the following creation of a plasma hull. Here, electrochemical and plasma reactions take place. It does not require any shaped tool and has the capability of achieving surface quality of Ra ≤ 0.02 µm when starting from milled parts. However, due to its current-density based localisation towards micro peaks, it is currently not efficient in removing large waviness. As it is shown, PeP is a suitable process to finish-machine AM parts and contributes to a tight tolerance chain, allowing to push AM of complex metal parts further towards general industrial use.

Additive Manufacturing, Plasma electrolytic Polishing, surface quality, surface integrity

1. Introduction

Additive manufacturing (AM) is considered a disruptive or key enabling technology. Polymer based AM using filament extrusion has attracted much attention from customer/maker side, but many industrial applications require parts made in metallic materials and consequently powder based processes. While these AM (SLM, EBM, DMD) processes become more and more reliable and the achievable accuracy shifts towards industrial applicability, the achievable surface quality is still insufficient. This process inherent challenge is based on partial melting and/or agglomeration of powder to the outside of the melt pool and the part, leading to high roughness values in the range of 10 µm ≤ Ra ≤ 30 µm. In combination with AM-specific complex designs (i.e. "complexity for free" approach) and the resulting inaccessibility of many surfaces for e.g. grinding tools, surface finishing to acceptable values of Ra ≤ 2 µm is difficult.

The recently developed Plasma electrolytic Polishing (PeP) process is based on a high DC voltage applied between part and an aqueous electrolyte and the following creation of a plasma hull. Here, electrochemical and plasma reactions take place. It does not require any shaped tool and has the capability of achieving surface quality of Ra ≤ 0.02 µm when starting from milled parts.

2. Plasma electrolytic polishing (PeP)

Plasma electrolytic processes have gained attention from metal finishing industries due to their capability to considerably enhance surface properties [1]. Amongst them, plasma electrolytic polishing (PeP) is an innovative surface treatment leading to very smooth, high-gloss surfaces with improved corrosion resistance. The PeP procedure was described for the first time in 1979 [2]. It is associated to the plasma electrolytic processes and seen as a special case of anodic dissolution [3,4,5,6]. PeP is primarily determined by the dissolution of the anode (etching / polishing) and plasma-chemical reactions.

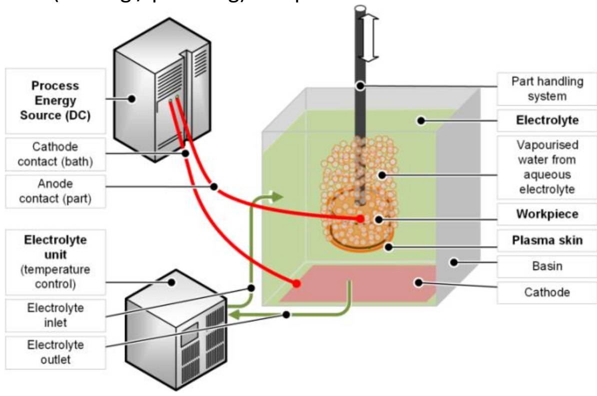

Figure 1. typical PeP process setup

In general, the workpiece is anodically polarized (u = 180...300 V, J = 0.2 A cm^{-2}) and immersed in a low-viscosity aqueous electrolyte solution. Its conductivity is adjusted to 4...30 S m^{-1} by the addition up to 12 % of various salts [7]. The relationship between current density J and applied potential u must be set to adjust the process window to the electro-hydrodynamic area for the PeP process. Caused by the process conditions, a plasma forms which completely surrounds the workpiece in the form of a vapour skin. The vapor skin results in the process surface temperature not exceeding the electrolyte boiling temperature; hence during the process the part reaches a maximum temperature of $\theta \leq 120$ °C.

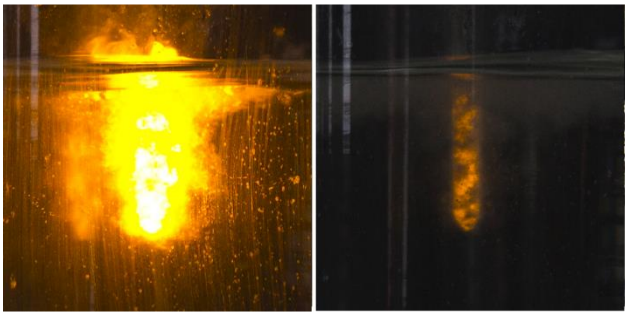

Figure 2. PeP ignition stage (left) and process stage (right)

3. PeP of AM parts

To make use of the full potential of AM technologies, part designs are incorporating thin struts, freeform surfaces, undercuts and other complex geometric features. PeP operates without the need for shaped tool electrodes and can therefore be applied, where mechanical polishing has reached its limit (Figure 2).

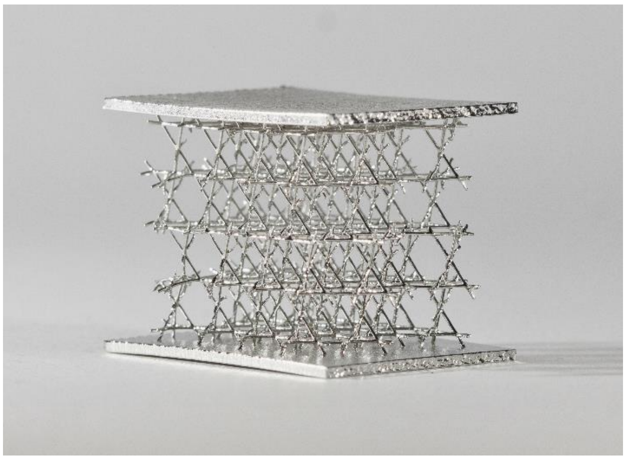

Figure 3. SLM part after PeP

In contrast to electropolishing, PeP also operates using nontoxic electrolytes, which is favourable considering AM applications in medical contexts. It could be shown that PeP does not act cytotoxic but slows down bacteria growth [8].

While PeP increases surface quality on the micro scale, it is limited in lowering waviness without increasing process time. Visible build steps in AM parts will be rounded and glossy, but not fully evened out. For surface finish of precision features on AM parts such as sealing surfaces, PeP should be applied after finish machining, where it can also remove burrs.

As PeP incorporates electrochemical removal mechanisms, an adapted electrolyte has to be used for each alloy, ensuring homogenous dissolution of all alloying elements. For common AM materials such as Inconel or maraging steel, developments are ongoing and first results exist. Furthermore, electrolytes for titanium parts are in the prototypical stage.

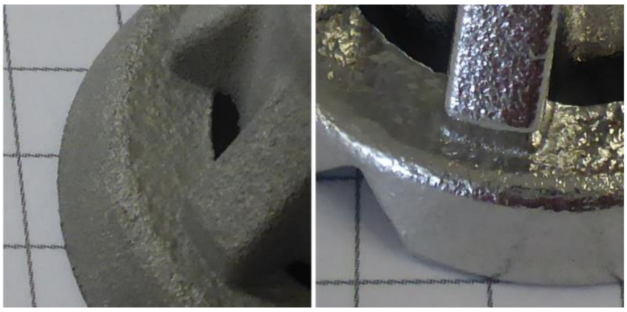

Figure 4. SLM part before (left) and after (right) PeP. PeP time 4 minutes. Grid dimensions are 5mm. Steel.

4. Conclusion and outlook

PeP is a promising technology to increase surface quality in AM parts. It can reduce roughness significantly, contributing towards biocompatibility, wear behaviour and higher fatigue strength. Investigations need to be conducted to correlate the efficiency of PeP with other surface treatment technologies in order to establish an optimal process chain for AM parts.

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